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ABSTRACT

Gaining a detailed and thorough understanding of the modern battle space is vital to the success of any military operation. Military commanders have access to significant quantities of information which originate from disparate and occasionally conflicting sources and systems. Combining this information into a single, coherent view of the environment can be extremely difficult, error prone and time consuming.

In this paper we describe the Naval Research Laboratory's Virtual Reality Responsive Workbench (VRRWB) and Dragon software system which together address the problem of battle space visualization. The VRRWB is a stereoscopic 3D interactive graphics system which allows multiple participants to interact in a shared virtual environment and physical space. A graphical representation of the battle space, including the terrain and military assets which lie on it, is displayed on a projection table. Using a six degree of freedom tracked joystick, the user navigates through the environment and interacts, via selection and querying, with the represented assets and the terrain.

The system has been successfully deployed in the Hunter Warrior Advanced Warfighting Exercise and the Joint Countermine ACTD Demonstration One. In this paper we describe the system and its capabilities in detail, discuss its performance in these two operations, and describe the lessons which have been learned.

KEYWORDS: interactive graphics, workbench, battle space visualization, virtual reality, user interface.

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Making Information Overload Work: the Dragon software system on a Virtual Reality Responsive Workbench

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March, 1998

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1   INTRODUCTION

Gaining a detailed tactical picture of the modern battle space is vital to the success of any military operation. This picture is used to direct the movement of assets and materiel over rugged terrain, day and night, in uncertain weather conditions, taking account of possible enemy locations and activity. To provide a timely and accurate picture of the battle space, most modern Command Operations Center (COC) have access to a multitude of

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systems which provide information from many different sources including eye witness reports, aerial photographs, sonar and radar. These disparate and sometimes conflicting sources must be combined together to present the tactical view. However, the quantities of information are sufficient that it is impossible for an individual to be able to collect and comprehend all the information. Typically, each information source is analyzed individually by a specially trained technician. The data sources are fused to give an overall view of the battle space which must be clear, concise, coherent, complete and accurate. However, the effectiveness of such a view is determined by its *usability*. If the picture contained all the information which had been collected the commanders would become overloaded by the quantitity of information. Currently most tactical decisions are made using detailed paper maps and acetate overlays. Printing and distributing these materials alone can take several hours.

In this paper we argue the problem of information overload in battle space awareness can be largely overcome using interactive, three dimensional computer graphics. By filtering the information which is displayed, it is possible for planners to examine the battle space across many levels of detail from a broad tactical picture to the details of individual units. Intuitive displays and interaction paradigms mean that it is possible to rapidly and accurately assess the situation. We describes the Naval Research Laboratory's solution to the battlefield visualization problem using a Virtual Reality Responsive Workbench (VRRWB) and the Dragon software system. The VRRWB is a 3D graphics system which allows multiple participants to interact in a shared virtual environment and physical space. A graphical representation of the battle space, including the terrain and military assets which lie on it, is displayed on a projection table. Through a careful use of models, user interaction metaphors and information displays, the system presents a detailed view of the battle space without overloading the user with huge quantities of information. The work was motivated by the needs of the Marine Corps Warfighting Laboratory (MCWL). In July 1996, NRL was asked by the MCWL to field a prototype situation awareness and planning and shaping tool for use in the Marine Corp's Sea Dragon project[4, 12, 13]. Since its participation in SeaDragon's Hunter Warrior Advanced Warfighting Exercise in March 1997, both the scope and functionality of the system have been significantly extended. The system was recently deployed at the Joint Countermine ACTD Demonstration One where it was used as a situation awareness tool. Given its success in these applications, the workbench has proved itself to be a valuable tool for next generation COCs.

The structure of this paper is as follows. The problem of battle space awareness is discussed in Section 2 and it is argued that 3D graphics with a high degree of interactivity is a very effective means of conveying the necessary information. Section 3 describes our solution which consists of an in-house developed software system (known as "Dragon") that is controlled by a user with a responsive workbench. Since the requirements of Hunter Warrior and Joint Countermine have largely complementary requirements, we briefly describe these applications and the experiences gained by the Dragon system in Section 4. Future work is described in Section 5. The paper is summarized in Section 6.

# 2   BATTLE SPACE AWARENESS

2.1   The Problem of Battle Space Awareness

Battle space awareness has been broadly defined by Blanchard as "knowing what is needed to win with the minimum number of casualties"[2]. This is an extremely broad concept and Blanchard identifies seven core concepts. Of these, our work addresses the problems of *terrain awareness* (detailed knowledge about the form of the terrain and its resources), *situation awareness* (including the situations of friendly and enemy forces as well as weather) and *mission planning and rehearsal systems* or MPRS.

The twin processes of acquiring terrain awareness and situation awareness can be very difficult. A Combat Operations Center (COC) receives many different kinds of information from many different sources. All of the different reports must be interpreted, reconciled and fused to give a consistent and comprehensive view of the battlespace. We believe that most battle space awareness systems must possess the following capabilities:
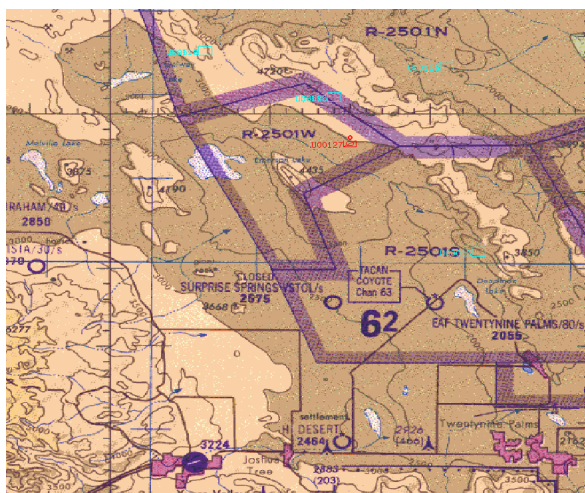
(a) Output from a JMCIS terminal.
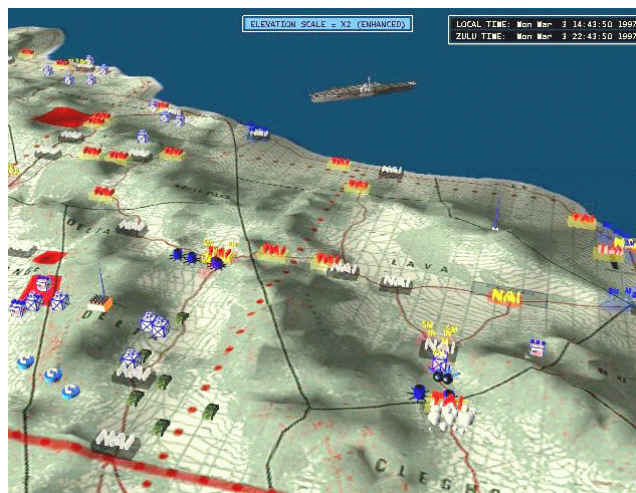
(b) Output from a Workbench.

Figure 1: Two and three dimensional displays of a simulated scenario

- Present a comprehensive and *timely* view of the environment.

- Provide a dynamic range of resolution sufficient to track units ranging from aircraft carriers to six-Marine fire teams.

- Support information filtering. In other words, it is possible to display a selected subset of available information using a particular display technique.

- Prioritize events and issue alarms.

- Represent limitations in the awareness. For example, data fusion procedures might be unable to classify a potential target or the position uncertainty could be very large.

- Provide the user with all of the information which is currently available.

- Support interaction with planning and simulation systems so that the current situation and future plans can be presented within a common framework.

2.2   The Limitations of Two Dimensional Displays

Historically, war fighters have used maps with acetate overlays marked with grease pencils to plan and update awareness of the battle space. Such methods are poorly suited for the modern day COC which receives many megabits of data per second from many different types of data sources. The concept of a computerized battle space visualization system is not new. The Joint Maritime Command Information System (JMCIS), is a widely fielded military information system which includes a visualization module. A JMCIS terminal is capable of displaying any type of information which can be stored within the JMCIS system including the position and classification of entitites. The information can be displayed in either tabular or iconic form. Figure 1(a) shows a typical output. The locations of approximately six entities are shown as icons which are superimposed on top of an ARC Digital Raster Graphic (ADRG) map. Each icon is color coded and labeled with the track number. The map provides detailed information about the terrain including its topology and the location of roads. Users can navigate by panning and zooming through the environment. Entities can be selected and queried using a mouse and pop

Figure 2: Some activity during the Hunter Warrior Exercise.

up menus. Although JMICS is extremely powerful and flexible, it has two significant problems for information overload and battlefield visualization — clutter and the loss of three dimensional information.

Clutter arises when the terminal is displaying significant quantities of information. In Figure 1(a) several entities lie sufficiently close to one another that their icons and track names overlap. Furthermore, the details on the map can make it difficult to determine the positions of the entities. Some of these difficulties can be overcome by changing the visibility options — for example, replacing the map by a monochrome background will make the positions of the entities clearer. However, these solutions *reduce* the amount of information which is displayed.

The second problem is that JMCIS only provides a plan view of the battle space. However, the battle space is inherently three dimensional and understanding the relationship between the terrain, ground assets, aircraft and flight corridors can be critical. For example, in the scene which is displayed the altitude of the ground varies by over a thousand feet. In a two dimensional display this information can only be revealed by studying the contour lines and reviewing altitude information for each entity.

We believe that these difficulties can be reduced by replacing the two-dimensional plan-based view by a three

dimensional display.

2.3   Three Dimensional Displays

Three dimensional graphical displays replace a two dimensional plan view by a full, three-dimensional representation of the scene. Through introducing depth into the environment, such displays can present much greater quantities of information. This can be appreciated by comparing the output from the Dragon system, shown in Figure 1(b), with that from the JMCIS terminal. At the instant shown both systems are displaying parts of the same environment (the 29 Palms Area which is discussed in more detail in Section 4). The 3D display represents the terrain as a contoured surface which is textured with an ADRG map. The form of the terrain can be directly observed without reference to the contour lines on the map. Entities are represented by icons and models which lie on and above the terrain. Contrast and depth cues highlight the positions of these entities against a cluttered surface. Finally, the user has much greater control over the viewport location and viewing angle.

Given its advantages, three dimensional graphical displays have been used for a number of years in MPRS applications. Most of these applications are "stealth viewers" — the user is a passive observer who can navigate through an environment and study a simulation from many different vantage points. However, these systems cannot meet the needs of battle space awareness systems for two main reasons. First, the types of data created by a simulation are different than those from received by a COC. The simulations only produce a few kinds of exact data with no ambiguities or uncertainties. Second, the role of the user in a battle space awareness system is much greater than that in a stealth viewer. The user is not just a passive observer — the user must also be able to play an extremely active role in querying entities and changing the state of the environment. Virtual reality (VR) is ideally suited for this type of task.

Although VR is usually discussed in the context of a fully immersive system with a head mounted display, the term is fairly broad and includes a number of different paradigms[11] which can be classified as *immersive*, *partially immersive or non-immersive*. Immersive VR systems use head mounted displays, push booms and immersive rooms[9] to the user the impression of being immersed within a synthetic environment. Non-immersive VR systems do not attempt to simulate a complete environment. The battle space awareness task does not require that command and control staff are immersed in a virtual COC. Rather, the types of tasks which are to be supported are those which are conducted at a desk. An ideal system for working with such tasks is the *virtual reality responsive workbench* (VRRWB)[5, 6, 8, 10] which is described in the next section.

3   THE NRL WORKBENCH AND DRAGON SOFTWARE

3.1   The Virtual Reality Responsive Workbench

The main components of a VRRWB are illustrated in Figure 3. A desk-side workstation renders a three dimensional image of the screen. This image is back-projected onto a horizontally mounted screen. Users stand in the viewing area and interact with the bench through a number of input devices including a tracked three dimensional mouse, a pair of pinch gloves and a speech recognition system.

The display system can operate in a monographic or stereographic mode. In the stereographic mode the display alternates between rendering images for the left and right eyes on each frame and each user wears a pair

Figure 3: The Virtual Responsive Workbench

of LCD shutter glasses giving each user the illusion that the project image rises above or sinks below the surface of

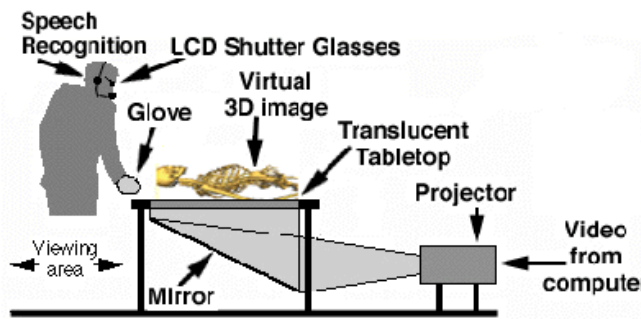the table. The perception of depth enhances the perception of the three dimensional structure of the environment.

The workbench is suited for the needs of battle space visualization. It creates a virtual environment ideally suited for fine grained manipulation and allows a number of users to collaborate in the same physical and virtual environments at the same time.

3.2 Display and Symbology

(a) Symbology used

(b) An Annotated Entity

Figure 4: Display symbology and marker types

The Dragon system presents the user with a three dimensional image of an abstraction of the battle space. Figure 2 shows a screen capture of some of the activity encountered in the Hunter Warrior AWE. It shows many of the essential features of the Dragon system — the terrain and coast line, a number of on-shore and off-shore military assets, the user's laser wand (described later) and information windows providing data about units and the current time. Considerable time and effort was devoted to developing a symbology which is intuitive, clear and meets the situation awareness needs.

The terrain contour information is derived from a Digital Terrain Elevation Data (DTED) Level 1 database. This data is used to construct a polygonal skin over which is draped a texture derived from an ADRG dataset. The latter is simply a digital form of the standardized maps which are used in a COC. The maps include the military grid system, contour lines, range markers, and other import designations that are used by the commanders in their day-to-day tasks. To give a greater appreciation of the form of the terrain, it is possible to scale the map in the vertical direction.

The Dragon system supports over 200 different models of military assets, some of which are shown in Figure 4(a). Since a standard has not yet been established for three dimensional tactical displays, the symbology was designed through discussion with a number of military commanders. Roughly half of our model suite is obtained from commercial sources and consists of models of complex equipment such as tanks, ships and helicopters. The remaining symbols were developed inhouse. Large units are represented by flags bearing the name and seal associated with that unit. Smaller units (platoons, squads, and fire teams, for example) are represented by simple cubes textured on all sides with standard military symbols such as an 'X' for infantry and a sideways 'E' for engineers. These are easily recognizable by the users. Since some percentage of the user base is color blind, it was necessary to use a combination of colors and symbols to differentiate between the different forces.

An important question is to decide the scale of the models which are displayed on the terrain. If the models are too small they can only be seen close up and it is not possible to obtain an overall view of the environment. Conversely, if the models are too large then the results can be misleading. Entity models could overlap one another (similar to the difficulties encountered by the JMCIS system). Initially the entities were all presented at the same scale. Our current system scales the entities between one and fifty times real size on demand. We plan to investigate a system which smoothly changes the entity scale as the user zooms in towards the terrain[7] and an aggregation system which will group entities together into a more encompassing symbol.

It is possible to query entities or the terrain for further information. We have developed two approaches. The first, illustrated in Figure 2 is a pop up display which provides information about the entity name, type, current status and other pertinent information. The second means of displaying information is to attach a status icon directly to the entity. This capability is illustrated in Figure 4(b) where the name of the entity is displayed as a flag.

3.3 Interaction Methods

Much of the success of a visualization system depends on the ease with which a user can navigate through the virtual environment and interact with objects. If the interaction is extremely difficult, performing tasks can be stressful and inefficient. These issues were crucial in the design of the system, where it was expected that users would be operating the system continuously for many hours at a time. We have experimented with three methods of interaction with the Workbench: gesture recognition with a pinchglove, a spaceball, a mounted joystick mouse and a three dimensional mouse which projects a virtual *wand*. The wand was chosen because of its ease of use (it is possible to stand in one position and select and highlight entities on any part of the visible display) and physical robustness (it contains few moving parts and does not rely on precise callibration).

Figure 5: The Virtual Responsive Workbench

Figure 5 shows a number of users working with the bench and its laser wand. The metaphor which we used was one of a laser pointer. The position and orientation of the pointer is tracked using an electro-magnetic tracker and a virtual ray, pointing in the direction of the wand is projected out onto the terrain. The wand can be seen in Figure 2 as a semi transparent tube which runs up from the bottom of the screen.

There are two basic tasks: change the viewpoint of the virtual environment and perform operations on the entities within the environment. We have introduced two complementary metaphors for navigation — *exocentric* and *egocentric*. In the exocentric metaphor, the user remains stationary and the map moves. In the egocentric view, which is akin to more conventional virtual reality navigation systems, the map remains stationary and the user "flies" through the environment.

The exocentric metaphor follows directly from the way in which a user interacts with a real physical map placed on a table top surface. If the map is too large to completely fit on the table, the user must move the map left, right and up, down in order to move the desired portion of the map onto the table top surface. In the Dragon system, one combination of buttons on the joystick provided a similar capability. A user presses a combination of buttons and moves the joystick parallel to the surface of the bench. The terrain mimics the user's motion and scrolls left/right or up/down. If the user moves the joystick away from the surface of the bench the scale of

the terrain increased, whereas moving the joystick towards the surface of the table causes the scale to decrease. Functionality was also available for the user to change his heading and pitch in the environment. Thus, the user was able to manipulate the viewpoint into the virtual environment very easily and was quickly able to achieve any desired viewpoint.

Although the exocentric metaphor is suited for global planning tasks, it is not well suited for those operations in which some degree of immersion is required. For example, it is difficult to fly over the terrain or position the viewpoint at the location of an asset on the terrain. To meet these requirements. an egocentric navigation metaphor was implemented. Under this metaphor, the user moves through the virtual environment. Since navigation with a full six degrees of freedom can be difficult, we have implemented three navigation modes. The pan/zoom mode moves the user in the direction of the mouse gesture. The pitch/yaw mode either changes the pitch or the yaw (heading) one is viewing. The final navigation mode is rotate/zoom to make it possible for the user to user to rotate around a specific object or point on the terrain. It is also possible to "tether" the origin of the viewpoint to an entity. If the entity moves, the view point moves by the same amount in the same direction. User studies are in progress to determine the most efficient, naturual and easy way to use navigation modes.

The user interacts with all entities on the terrain with the virtual laser wand. An entity is selected by pointing the wand at the entity in question. As shown in Figure 2, the highlighting is signified by drawing a wire frame sphere about the appropriate entity. Once an entity has been selected, the user can perform several actions. First, the entity can be queried to find out further information such as its name, track number or status information. This basic functionality is required when the user is a passive observer. When the user plays a proactive role (in, for example, a planning application) the user will be able to create, pick up, move and place entities on different parts of the terrain. By pressing a button on the joystick, the user picks up the selected entity and moves it around the virtual environment. Entities suspended above the terrain project a red drop line to the surface to indicate position and altitude. Terrain-based entities such as tanks or ships drop to the terrain surface when released; other entities (such as aircraft) remain at the same position.

3.4 Software Architecture

The development of the Dragon system introduced a number of challenges. First, it receives information from many different data sources including simulations and situation awareness systems. Each data source has its own characteristics (the types of data it provides, the queries which can be made and the update rates) and they must be converted into a common format which can be efficiently stored and processed. Second, it must be possible for the system to render a large and complicated graphical scene with an interactive frame rate (more than 10 frames per second). To meet these objectives, we designed the system whose architecture is illustrated in Figure 6. Finally, the computing power required cannot exceed the capacity of current desk side workstations. The system consists of two key components: an *entity manager* and a *rendering engine* which communicate through a high-speed shared memory arena.
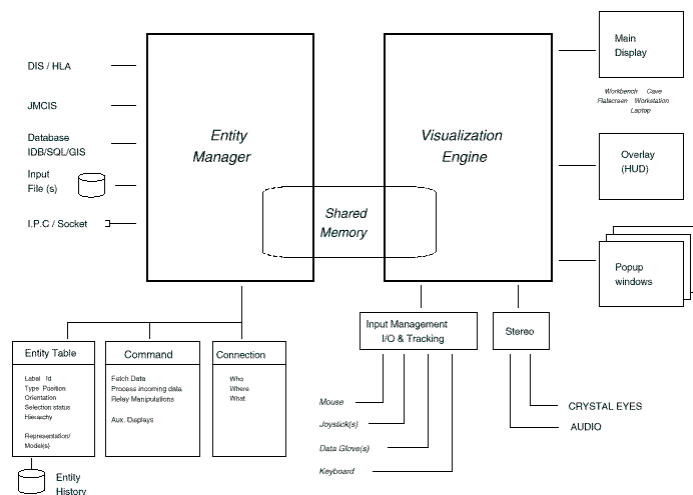
Figure 6: The Architecture of the Dragon System.

The asynchronous entity manager is the interface between the external data systems and the rendering engine. It collects the data from the different sources, parses it to a common representation and builds a table of current

entities. To minimize the amount of information which flows between the manager and the renderer, only entity state changes are communicated. To control user access operations, each entity has a set of permissions associated with it. These permissions are used to manage the different needs and requirements from different systems. For example, in a battlefield awareness situation it is not desirable for a user to be able to move the entities which arise from external data feeds. However, in a planning and shaping application it is necessary that the user be able to move them. Currently, the entity manager accepts input from GCCS-M, DIS and persistent data storage. Proposed data systems include Entity Manager to Entity Manager communications (allowing collaborative, multi-user distributed systems) and distributed intelligent agent architectures[3] which make it possible to interact with agent based systems such as QuickSet or multimodal interaction systems.

The rendering engine manages all user interactions and has two key roles. The first is an input function — it collects the data from the tracking devices and detects whether the wand is intersecting with the entities or the terrain. Second, it renders the images which are seen by the user. To achieve the required frame rates we developed a custom renderer which is built on top of Silicon Graphic's Performer library.

4   SAMPLE APPLICATIONS

In this section we describe two applications of the workbench and the Dragon software — the Hunter Warrior AWE and the Joint Countermine Operational Simulation (JCOS). Together, these applications demonstrate the system's capability for terrain awareness, situation awareness and MPRS.

4.1   Hunter Warrior

4.1.1   Operational Objectives

NRL was approached in July 1996 by the Marine Corps Warfighting Laboratory to produce a prototype system for the Hunter Warrior Advanced Warfighting Experiment (AWE) which was held in March 1997. The Hunter Warrior AWE is the first of a series of three AWEs that make up the SeaDragon process, a program to explore technology and its roll in supporting the Marines in the 21st century. NRL delivered the first version of the Dragon software to MCTSSA, Camp Pendleton, CA during the first week in December 1996. A final version was delivered in mid-February 1997 and included a near-realtime interface to import a Joint Maritime Command Information System (JMCIS) data feed.
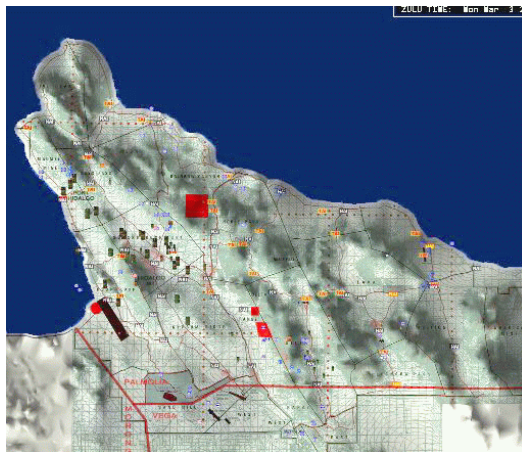

Figure 7: Plan View of 29 Palms

The operational portion of Hunter Warrior, shown in Figure 7 took place at the Twenty-nine Palms National Training Center, California. For this exercise, the Marines simulated a regional conflict between two neighboring countries, one of which had coastal port facilities. These port facilities were important for rapidly off loading large equipment to support the Marines landing. Since these port facilities do not exist in the real environment (Twenty-Nine Palms is in the high desert of Southern California), the terrain dataset was modified to introduce an artificial coast line.

4.1.2   Results

Despite the fact that the delivered system was a prototype, we received very positive comments from commanders and technicians alike. Throughout the exercise the system was used almost continuously and, by the end of the exercise, the marines were using the workbench in preference to paper maps and acetate overlays. In
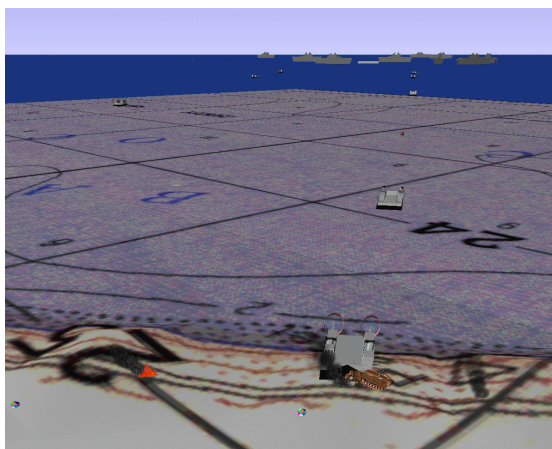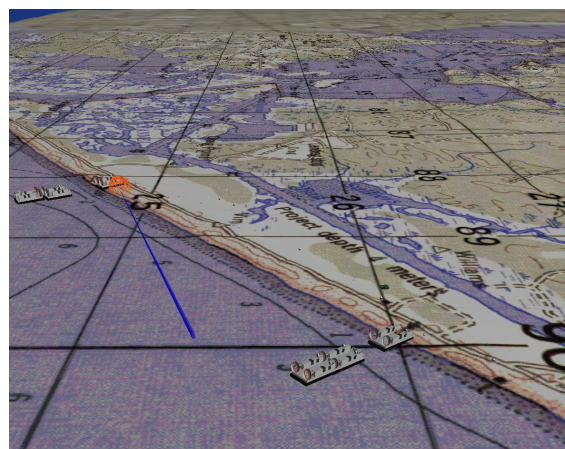
| (a) JCOS in operation | (b) Close up of activity |

Figure 8: Screen shots from the JCOS exercise.

addition to its primary role as a situation awareness tool, the workbench was also used as a briefing tool.

Colonel Wood, Director of the Marine Corps Warfighting Laboratory, wrote "I consider the capability provided by the workbench to be a seminal, critical break-through over previous technology and competing systems. This fact became even more obvious as we demonstrated its capability for the several hundred VIPs who all commented on the workbench's tremendous potential."

4.2 Joint Counter Mine Operational Simulation

4.2.1 Exercise Objective

Between the 18th of August and the 5th of September 1997, Dragon was used to support the Joint Countermine Operational Simulation (JCOS) component of the Joint Counter Mine (JCM) ACTD. The purpose of JCM is to measure the effectiveness of nine novel techniques for mine clearance in combat situations. A set of simulated exercises were conducted at Camp Lejeune, North Carolina, and the Dragon system was used as a viewer to aid in the analysis of the archived data. Since it was being used as a stealth viewer, users were not able to change the state of any entities. Although this was less demanding from the perspective of entity manipulation techniques, it introduced a number of new challenges with the navigation modes, labeling and annotations, continuous updates of over three hundred entities and the ability to provide real-time animation of events such as explosions and smoke.

4.2.2 Results

Figure 8 shows two screen shots from the exercise. Unlike the Twenty-Nine Palms Area, Camp Lejeune is extremely flat (the highest point in the data set is a man made hill which is under 20m in height). Therefore, the problem of terrain awareness is limited. The Workbench was situated in a small room off of the main control and briefing area. Almost all of the VIPs, both civilian and military, commented on the potential for the workbench to provide a thoroughly integrated visualization environment for multiple data streams that would greatly assist the user in performing his or her tasks.

5   FUTURE WORK

The experiences which we have obtained from this work suggests that there are many further areas of research and development to explore. Some of the most important ones are:

- Extend the size of the terrain dataset which can be represented through the use of wide area database management techniques.

- Increase the resolution of the terrain.

- Increase the types of interaction technology which can be used with the workbench. Such technologies include speech, natural language recognition, haptic (force feedback) devices and tracked laser pointers.

- Investigate the visualization of different types of data using different display technologies including techniques such as overlays, gauges, color, texture and sound.

- Develop multi-user workbenches. These are capable of displaying different views to two or more workers[1]. There are a number of different potential uses including two or more tracked views and information filtering.

- Provide simple representations of the weather to take into account the effects of fog and cloud cover.

6   CONCLUSIONS

Modern day COCs are flooded by gigabits of information from many different information systems. Military commanders and planners must filter this information to determine a consistent and accurate picture of the battle space for situation awareness and MPRS. However, the sheer volume of this raw data can lead to information overload. This situation will only become worse as more sources of data become available.

In this paper we have argued that the problem of information overload can be overcome through a combination of carefully designed user interfaces and visualization displays. These make it possible for a user to filter the data such that only information relevant to a particular stage of a planning process is displayed as required. The workbench, which supports the paradigm of desk-based work with multiple collaborators, is ideally suited to the problems of situation awareness and MPRS. The performance of our Dragon software system has been demonstrated in a number of military exercises.

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